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by

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Abstract:

Irrigation water demand elasticity is estimated based in a large panel dataset on an Irrigation District in Emilia-Romagna region, one of the most important area for agricultural production in Italy The model is applied to subsamples of irrigation technologies, crops and representative combinations of crops and irrigation systems and controlled for autocorrelation and heteroscedasticity by using a fixed effect model and a Feasible General Least Square regression. results show heterogeneity of water demand price elasticity according to different crops and irrigation systems. The main finding is the fact that water price elasticity increases with the level of water supply control (i.e. it is more elastic with drip vs. furrow) implying that response to water pricing is less effective with traditional irrigation technologies.

1- Introduction

The international debate on pricing water as a measure to cope with water scarcity started in 1992 with the Dublin principles during the United Nation International Conference on Water and the Environment (United Nations, 1992) in which water was declared as a social good with an intrinsic economic value to be managed sustainably (Savenije and van der Zaag, 2002; Somanathan and R. Ravindranath, 2006). In the last three decades' economic measures started to be implemented as a tool for environmental policies in water resource management based on the polluters pay and user pay principle (Lago et al., 2015; Renzetti, 2002)

Water pricing is an economic tool that stimulates farmers to reduce water use and optimize its allocation (Wheeler et al., 2015). Volumetric tariffs can lead to modification of farmer water strategies such as crop substitution (Varela-Ortega et al., 1998) or technological change (Pronti et al., 2020) reducing overexploitation by assigning opportunity cost to water as an input and guiding water allocation towards the greatest economic return (Ward and Michelsen, 2002). Additionally, water price has an important financial role in creating revenues for the supplier (Saleth and Dinar, 2005) and implement cost recovery principles (Dinar and Mody, 2004; Rogers, 2002).

Assigning a price to each volume of water demanded can also reduce the cost of setting and controlling the policy effect, because profit maximizer farmers should adapt consequently water demand to their own real cost function (Dinar and Mody, 2004; Massarutto, 2003) . Irrigators will adapt to changes in water prices basing on their own marginal adjustment costs, reducing the aggregate cost of the policy more than with regulatory instruments which target farmers indiscriminately. Moreover, economic tools create permanent incentives to technological innovations more than regulation methods which provide incentives to innovate until compliance is achieved (Lago et al., 2015). Volumetric tariffs had been used as a principal economic measure toward sustainable water management, but with ambiguous results in terms of real water consumption with high differences among different cases of application (Cooper et al., 2014; Dinar and Mody, 2004; Molle and Berkoff, 2007).

Effectiveness of water pricing depends upon demand characteristics and specifically on price elasticity. Price elasticity of demand is a measure of the change in the quantity demanded of a product in relation to its price change (Olmstead et al., 2007). Water price elasticity is extremely important for policy making in agricultural water management in terms of responsiveness of farmers to institutional incentives in water use for crop production (Somanathan and R. Ravindranath, 2006; Wheeler et al., 2008). Wrong assessment of water demand elasticity can conduct to pricing policy failures due to overpricing water, lowering farmers income because of high water costs, or underpricing water, assigning too low opportunity costs incentivizing over-irrigation (Molle, 2009).

The effect of water price elasticity on the total quantity of water demanded is still not clear in literature with heterogeneous results of empirical analysis which depend on different local conditions linked to water systems and other aspects such as socio-economic, geographical and institutional factors (Scheierling et al., 2006). Little applied research has been done related to this aspect which influence the availability of effective analysis on the outcomes and impacts of water policies (Massarutto, 2003).

The objective of this paper is to analyze water demand elasticity of farmers considering heterogeneity of agricultural production and irrigation systems thorough an empirical analysis using a large observational panel dataset at plot level of an Irrigation Water District (IWD) in northern Italy. We used different econometric models to assess water demand elasticity to price considering different technologies, different crops and a combination of them, while controlling for weather conditions and other heterogeneities among observations.

Panel data econometric methods, can partially account for unobserved factors with estimates which are not deterministic but based on stochastic process. Literature on water demand elasticity offered different works based on econometric analysis, but they still are a limited part of the total work principally because of lack of observational data. According the review made by (Scheierling et al., 2006), econometric estimation of irrigation elasticity are mainly based on cross section analysis. At the best of our knowledge our study is the vastest analysis in terms of dataset and variety of crops and technologies considered using a panel data approach.

The paper is structured as follow. In section 2 a brief state of the art of literature on water demand elasticity is presented, in section 3 materials and methods are discussed, in section 4 results of the analysis are presented, section 5 introduce a discussion over the main findings and the paper finally finish with section 6 with concluding remarks.

2- The price elasticity of water demand in agriculture

The main element of uncertainties in water pricing policies in agriculture is linked to the response of farmers to the policy which principally depends on their reactions to water price changes. Knowing water demand elasticity is fundamental for the effectiveness of water price policies and to formulate ad hoc intervention in order to improve water use efficiency reducing pressures on water resources, while considering the overall effects on farmers' incomes and the raised revenues by the policy (Iglesias et al., 1998).

Water demand elasticity is a highly debated issue in agricultural water management literature in which are present conflicting conclusions. Agricultural water demand depends mainly on physical productivity of water, farmers' incomes, local environmental conditions and market structure. Moreover, other not directly observable factors may also influence water demand such as social, institutional and behavioral aspects (Massarutto, 2003). Those elements can have high variability among countries and regions depending on geographic, socio-economic, financial, political and infrastructural conditions constraining considerations on water demand and elasticity to single case by case studies (Dinar and Mody, 2004; Molle and Berkoff, 2007).

Scheierling et al. (2006) accomplished a meta regression analysis on the all available study at the time of their study (over 24 studies, published from 1963 to 2004) finding a relevant variety of results on elasticity which depend mainly by case study factors. They found an average water demand elasticity to price of -0.48, indicating that water demand are on average inelastic, but they found a relatively large standard deviation of 0.53 with range in absolute term between 0.001 and 1.97 (Scheierling et al., 2006). Zuo et al. (2015) confirmed those results with a contingent evaluation in Australia estimating a water demand elasticity of -0.57 considering long term water entitlements. Conversely, considering the same area, Zuo et al. (2016) found farmer water demand elastic to water prices with ranges from 0.73 to 3.23 with differences among geographical, demographic and productive farms characteristics. The main differences in the two studies is that in the latter elasticity is calculated considering willingness to accept farming exit prices, which can substantially differ from normal water demand elasticity to price.

Some scholars claimed that water demand is totally inelastic (Massarutto, 2003; Moore et al., 1994; Ogg and Gollehon, 1989) others that water demand is elastic (Schoengold et al., 2006) or elastic only for underground water, but not for furrow irrigation using gravity irrigation (Nieswiadomy, 1985). Other studies found that water demand is elastic only after a certain price threshold whereas it is inelastic below that point (Berbel and Gómez-Limón, 2000; Varela-Ortega et al., 1998). Wheeler et al. (2008) estimated an average elasticity for bid water demand of -1.5 considering Australian water markets and using time-series of total water market allocations highlighting important fluctuations within the irrigation season (-1.71 to -4.14) and during months. They had estimated a short term elasticity at mean of -0.52 and -0.89 for long term. In a recent study de Bonviller et al (2020)based on Australian groundwater markets found a unitary elasticity of -1.05 . They highlighted also that price is not the sole important driver in water demand, but also drought, price of products, season, other inputs related to irrigation (such as diesel prices or electricity) and type of crop influences farmers demand (de Bonviller et al., 2020; Wheeler et al., 2008).

In general, empirical studies present in literature indicate that water demand is inelastic for both low and high changes in water prices and that mainly the water demand curve is not strongly respondent to water pricing policies because of a general low water demand elasticity of farmers (Dinar and Mody, 2004; Molle and Berkoff, 2007). Moreover, water price to have response effects should be fixed at too high levels which would affect more agricultural incomes than its possible positive effects on the environment and water savings (Berbel and Gómez-Limón, 2000; de Fraiture and Perry, 2007). Conversely other studies stated that, despite structural levels in which water demand is inelastic, water prices can be effective because of high elasticity of water demand segments (Gómez-Limón and Riesgo, 2004). Water demand elasticity is affected by threshold effects in which for low water prices ranges water demand does not respond to higher prices, for medium prices ranges change water demand do respond to prices because of farmers' strategies changing to water conservation and saving technologies (WCST) (Pronti et al., 2020) or low water needs crops, whereas for high prices ranges water demand turn to be inelastic because of the exit of the market of the farmer (de Fraiture and Perry, 2007; Gómez-Limón and Riesgo, 2004).

Threshold effects depends at low level of prices on technical substitution effects (of technology and crops) which reflect changes in input composition within the farmer production function. Those changes determine the elasticity part of the demand curve which represent substitutions of water with capital and labor as a strategy adopted by the farmer to cope with increasing prices of water (Renzetti, 2002) . At certain price levels, the demand curve become inelastic again because of the end of input substitution possibilities and increasing disadvantages in agricultural productions due too high opportunity cost of water (Berbel and Gómez-Limón, 2000, p. 200; de Fraiture and Perry, 2007). Therefore, there is not complete agreement in literature on the effect of pricing water on water demand and then on the response effect of tariff policy on farmers' irrigation decisions (de Fraiture and Perry, 2002; Molle and Berkoff, 2007).

In empirical works water demand elasticity has been derived using different methods. The studies present in literature are divide principally into Mathematical Programming (MP), Experimental Studies and Econometric analysis.

One of the main problem in this field of study is the very low level of reliable pieces of information on both water prices and water demand. The absence of observations over a range of different prices encouraged scholars to use MP methods (linear, quadratic and stochastic approaches) for deriving water demand elasticity using simulation of optimization models (Bontemps and Couture, 2002)). The main way for extracting elasticity measures with mathematical programming is through the derivative of the dual solutions which can be considered as the water shadow prices (Elbakidze et al., 2017; Howitt et al., 1980). Mathematical Programming has been frequently used to estimate water demand with the first examples assuming profit maximization and recently, mathematical programming has integrated more realistic assumptions trying to adapt to observed decisions such as PMP and MCDM,, for a better real representation irrigation can be considered as a stochastic process and not completely deterministic (Antle and Hatchett, 1986; Wheeler et al., 2015).

Because of the main limitations on agricultural water data, most of the econometric analysis present to date in literature are principally cross sectional and aggregated at higher level than plot which can bring to under estimated results of water elasticity (Bontemps and Couture, 2002). At the best of our knowledge only the work of Schoengold et al. (2006) deals with estimation of water demand elasticity using a panel data approach.

3- Material and methods

3.1Case study and data description

In Italy the lowest institutional level of agricultural water management is hold by the Irrigation Water Districts (IWD Consorzi di Bonifica in Italian). IWD are private-public institutions which have born as irrigators associations in the beginning of the last centuries (Bazzani et al., 2005). IWD have taken over time increasing institutional importance in national water management system until being entrusted by the national law (Legislative Decree 152/06 Environmental Code**)** in addressing the WFD at local level (Dono et al., 2019). Nowadays, IWDs are in charge for the implementation, development, maintenance and management of the irrigation systems for the farms located in their assigned area (Dono et al., 2019; El Chami et al., 2011). There are around 500 IWDs in Italy with many differences in management systems, dimensions and tariff systems. and in accordance to regional laws they must set the price of water services to their users (Berbel et al., 2019). The 63% of water withdrawn for agriculture come from IWD, of which 34% is with turning system and 29% is on demand service, whereas the rest 37% is from groundwater (18%) and private superficial sources (15%) (Istat, 2014).

Emilia-Romagna Region (ERR) has the largest share of irrigated land in Italy and the agricultural sector of ERR is one of the most important productive area of the country (Pérez-Blanco et al., 2016). In 2017 the value added of agriculture in ERR was the 11% of the national value with a total value of production of 4.8 billion euros (ERR, 2019a, 2019b; Fanfani and Pieri, 2018). The role of irrigation is crucial for the regional production system and during the last decades agricultural development strongly increased pressures on water resources (Pérez-Blanco et al., 2016). Moreover, ERR has been affected by important repeated extreme events due to strong droughts events during the cropping season since 2003 (Vezzoli et al., 2015).

ERR regional government implemented several policies based on incentives and regulations for improving the conservation of water resources boosting improvements in irrigation efficiency and reduction of pollutants. Among various interventions an important role has been taken by the introduction of pricing instruments for irrigation guided by the Cost Recovery Principle (El Chami et al., 2011).

The data base comes from water prices and water distribution of the Central Emilia Irrigation Water District (CEWD in Italian *Consorzio di Bonifica dell'Emilia Centrale*) in the provinces of Reggio-Emilia and Modena in Emilia-Romagna region (Italy).

The area served by CEWD has the highest level regional production value (ERR, 2019a) in which are produced many important high-valued certified agri-food products (such as Parmigiano-Reggiano cheese, Balsamic Modena Vinegar, Lambrusco wine and crops with Protected Geographical Indication) (ERR, 2019b). The CEWD is in charge for water distribution of local farmers with a complex infrastructural network diverting water from the rivers Po, Secchia and Enza and serving thousands of farmers annually (CEWD, 2017, 2015). The most important crop cultivated in the area are: Alfalfa, Maize, Meadows, Vineyard and Orchards (principally pear and a minority of apple, peach and others), other crops grown are: Soya, Sugar Beet, Tomato and Watermelon. The principal irrigation system adopted is sprinkler, whereas for specific crops drip is used (Watermelon, Vineyard and Orchards) and for others furrow is the main irrigation system (Orchards and Vineyard). In table 1 average values per crop and irrigation system of observations, water used, water tariffs and irrigated land within the CEWD are resumed.

Table 1. . Mean Irrigated areas and water price considering Crops and Irrigation systems.

Crop	Irrigation system	Irrigated Area (Ha)	Water Volume (m^3 per Ha)	water tariff(€)	n obs.
Alfalfa	Drip	3.61	775.82	0.0238	10
Alfalfa	Furrow	3.53	1225.51	0.0253	235
Alfalfa	Sprinkler	4.74	1023.30	0.0226	3339
Maize	Drip	1.82	1184.19	0.0204	49
Maize	Furrow	2.53	3575.39	0.0321	99
Maize	Sprinkler	3.60	1298.57	0.0230	3947
Meadows	Drip	5.18	1686.91	0.0222	1
Meadows	Furrow	4.92	1277.90	0.0245	5895
Meadows	Sprinkler	6.48	1199.32	0.0244	150
Orchards	Drip	2.40	7695.00	0.0000	817
Orchards	Furrow	2.70	4604.92	0.0258	225
Orchards	Sprinkler	2.82	2234.76	0.0220	1511
Soya	Drip	3.67	1469.49	0.0284	2
Soya	Furrow	1.96	2854.30	0.0289	18
Soya	Sprinkler	2.96	1977.25	0.0278	405
Sugar Beet	Drip	1.73	888.83	0.0248	2
Sugar Beet	Furrow	5.14	1430.06	0.0236	20
Sugar Beet	Sprinkler	5.36	1010.33	0.0253	796
Tomato	Drip	2.65	334.09	0.0274	80
Tomato	Furrow	6.20	996.45	0.0273	5
Tomato	Sprinkler	5.63	849.53	0.0260	486
Vineyard	Drip	6.25	341.22	0.0251	1578
Vineyard	Furrow	3.74	1259.20	0.0238	3031
Vineyard	Sprinkler	5.85	846.79	0.0261	6178
Watermelon	Drip	8.30	1504.83	0.0249	236
Watermelon	Furrow	4.65	4188.69	0.0249	3
Watermelon	Sprinkler	6.64	1886.76	0.0246	73

General descriptive data shows that generally, for the same crop the water use is lower with drip and higher with furrow, with sprinkler in the middle, this is an expected result of the water saving achieved by the increased precision in irrigated systems. Irrigation demand is made directly by farmers to the CEWD which calculates the total amount of water to be diverted to the plot considering an irrigation plan compiled annually by the farmer with details on irrigation system and the crop plan. Therefore, water demand is not controlled by the farmer in the fluxes, which are optimized by the CEWD supply, but in the amount of how many times they ask for irrigation during the year. Direct water metering is not possible in the area as water is served principally through open canal systems, therefore each water supply is measured indirectly considering the canal flow rate, the capacity of the water structure, and the duration of the delivery (CEWD, 2017).

During the years the CEWD experimented different tariff schemes. CEWD was established in 2009 by the fusion of two previous IWDs present in the area (the *Consorzio di Bonifica Parmigiana Moglia Secchia* and *Bentivoglio-Enza*) in which irrigators were facing different water tariff schemes (flat and two-part tariffs) which have not been modified until 2015. In 2016, in conformity with its own sustainability aims, which are in line with the WFD, the CEWD implemented a new pricing plan based on a two-tariff scheme for all its users in order to reduce over irrigation and gather financial resources for covering operational and maintenance costs using a cost recovery approach. The new two-part tariff scheme is composed by a fixed fee to cover the general service of CEWD and a volumetric part based on a baseline price (BP) multiplied by an economic multiplier calculated with different coefficients which consider different type of service costs, water intensity of the crop and rivalry on water resources. The new tariff two-part scheme is synthetized shown in equation 1. All the tariffs applied in the CEWD during the years are presented in Table 2.

$$WP = BP * (RIV * SER * MOM * WI) \qquad \text{(eq.1)}$$

Where:

- WP is the water price of the two-part tariff applied within the CEWD since to 2016 to each water request.
- BP is baseline price of 0.025 €/m^3 in 2016, 0.027€/m^3 in 2017 and 2018.
- RIV is the coefficient for rivalry on the water resources. It is applied for areas of Secchia and Enza water basin in which droughts have higher probability to arise with limited water flows in periods of demand peaks. The coefficient increases the price by a level of 1.15 of BP, if rivalry does not occur RIV is equal to 1.
- SER is the service coefficient and it works as a recovery operational and maintenance costs in areas where water withdrawal is more energy intensive (in some area of Enza water basin). The coefficient increases the price by 1.2 of BP, if the user is located in a normal area SER is equal to 1.
- MOM is the momentum coefficient which considers out of season provision services to recover operational costs when the all the water irrigation systems of CEWD is not still fully operational. The coefficient increases the basic price by a range between of 1.2 and 1.5 of BP, if the request is made on-season periods MOM is equal to 1.
- WI is the crop water intensity coefficient which considers the crop water intensity in its production cycle, it ranges from 1.1 for medium water intensity crop (such as watermelon, apples, maize…) to 1.3 for high water intense crop (such as peaches, rice or Kiwi). Neutral water intense crops have a WI equal to 1.

Table 2.Tariff schemes in the CEWD during the years with frequencies and Water basin.

Period	Tariff scheme	Price € per m3	Frequency	Water Basin
2009-2015	Flat tariff	0	2,570	Po
2009-2015	Volumetric	0.0248358 €	4,596	Po, Secchia
2009-2015	Volumetric	0.025080 €	7,266	Po, Secchia
2009-2015	Volumetric	0.0436944 €	255	Enza
2009-2015	Volumetric	0.0441389 €	399	Enza
2016-2018	Two-part	0.02508 € * cost recovery coefficients	5,125	Po, Secchia, Enza
2016-2018	Two-part	0.027 € * cost recovery coefficients	10,232	Po, Secchia, Enza

All the different price tariffs applied over the years gave a varied range of applied prices for volumetric water use from 0 to 0.0489€ which is a small price range, but it can be used for analyzing farmers water use behavior in the short run building a water demand curve with good level of details for both different irrigation schemes and crops. We used the water demand curves for analyzing water demand elasticities to price using real observational data with panel data econometric methods. We based our analysis on the database of water provision directly released by the CEWD which record in its database for each request of water.

External climatic data have been merged considering georeferenced data of the municipality where the plot was located using the ERA-Interim dataset of the European Centre for Medium-Range Weather Forecasts (ECMWF) with 25km^2 grid cell spatial resolution including different weather variables at seasonal level (maximum and minimum temperature, accumulated precipitations and reference evapotranspiration) (ECMWF, 2020). The observations of CEWD dataset represent the universe of the water demand managed by the CEWD in the area for surface irrigation. Water requests have been aggregated at yearly level considering the total amount of water demanded for the plot during the year. Water prices are the average volumetric water price payed for irrigation of the plot in the year considering differences on price formation as explained above. The final panel is unbalanced, it considers a timeframe of six years from 2013 to 2018 with totally 28,738 observations and 9,097 different plots. Data have been aggregated at yearly level.

3.2 Theoretical framework and methodological approach

Elasticity can be defined as the dependent variable percentage change of a function caused by a unitary change of one of its independent variables. Demand elasticity of a good to price measures the responsiveness of the demand function to its price, it indicates the relative change in the quantity demanded due to a unitary change of price and it can be interpreted as a measure of responsiveness of the demand function to price changes (Varian, 1990). Usually elasticity is defined as the ratio between the variation of percentage quantity demanded and the percentage variation of the price (equation 2).

$$\varepsilon_d = \frac{\Delta_q/_q}{\Delta_p/_p} = \frac{\Delta_q}{\Delta_p} * \frac{p}{q} \qquad \text{(eq.2)}$$

Elasticity can be thought as the ratio between the slope of the demand curve and the ratio between price and quantity (Varian, 1990). In a single point, elasticity can be well approximated by the partial derivative of the demand function in respect to price or by the ratio between the marginal function and the average function of the demand function (equation 3) (Chiang and Wainwright, 2013).

$$\varepsilon_d = \frac{\partial Q}{\partial P} = \frac{dy}{dx} \Big/ \frac{q}{p} \qquad \text{(eq.3)}$$

Usually the value of elasticity is negative as the relationship between quantity and price is negative, whereas its magnitude indicates the level of responsiveness of the function to a unitary change of the depended variable. It is well established that an elasticity value in absolute term of 1 indicates constant elasticity with a proportional reaction of q for a change of x in 1 unit, a value in absolute term higher than 1 indicate that the curve is elastic which suggest a more than proportional response of q to unitary changes of x and a value in absolute term lower than 1 indicates an inelastic curve which suggest a less than proportional response of q to unitary changes of x (Chiang and Wainwright, 2013). The values of elasticity change along the curve and therefore in analyzing the overall elasticity of a function we should refer to the average elasticity of the curve (Iglesias et al., 1998).

Geometrically water demand elasticity can be thought as the reciprocal of the slope of the water demand curve. Steep demand curves will have small changes in water demand because of low elasticities, conversely flat water demand curves will experience great reactions to water price changes (either increases or decreases) because of high elasticities (Olmstead et al., 2007).

Various econometric models have been developed in order to capture water demand elasticity in agriculture using real observed data. The basic model used to capture elasticity with econometrics are log-log models which well fit the rate of change of the dependent variable due to a change in the covariates (Greene, 2018). Log-log models are defined using the logarithm of the dependent variable and logarithm of the independent variable of interest, while controlling for other factors. They are basic econometric approaches, but very effective in approximating the partial effect of an independent variable on the dependent variable (Wooldridge, 2010).

In a stochastic framework the partial effect of an explanatory variable x_j can be considered as the effect on the conditional expectation on the dependent variable $E(Y|X)$ by an infinitesimal change of x_j holding all the rest of variables constant and in linear models this is expressed by the estimated parameter of the variable of interest coefficients in the econometric equation(Wooldridge, 2010). Elasticity in a linear regression models can be defined as the average values of the dependent variable Y change as each single independent variable changes and it can be approximated by the partial derivative of the independent variable of interest holding the rest of *X* variables constant as in equation 4.

$$\Delta E(Y|X) = \frac{\partial \mu(x)}{\partial x_j} * \Delta x_j \qquad \text{(eq.4)}$$

Where the change of the conditional expectation value of Y on X is the partial derivative of μ in respect to x multiplied by the change in x and assuming that μ is a differentiable function which determines the realization of *Y* and x_j is a continuous variable (Wooldridge, 2010). Elasticity is a particular case of partial effect. Considering the variables of the model as random we can define elasticity as in equation 4 interpreting it as the approximate percentage change in $\Delta E(Y|X)$ due to a unitary change of xj and which can be defined through the use of logarithms (equation 5).

$$\frac{\partial E(y|x)}{\partial x_j} * \frac{x_j}{E(y|x)} = \frac{\partial \mu(x)}{\partial x_j} * \frac{x_j}{\mu(x)} \cong \frac{\partial log[\mathrm{E}(y|x)]}{\partial \log(x_j)} \qquad \text{(eq.5)}$$

Therefore, the estimated parameter coefficient β in the econometric model specified in the form as $\log(Y) = \beta \log(X) + \varepsilon$ releases the elasticities of the dependent variable *Y* in terms of each *X* explanatory variable (Wooldridge, 2010).

In this analysis we used the Log-Log specification exploiting a vast panel dataset available at plot level. Using plot level can solve for many problems related to bias of level of higher geographical aggregation. Moreover, the use of a fixed effect method helped us in considering unobserved heterogeneity which could cause endogeneity problems (Wooldridge, 2010). Our baseline model is a linear regression fixed effect model (equation 6) which uses as dependent variable the logarithm of the total yearly water demand at plot level and as independent variable of interest the logarithm of the yearly average price of water for each cubic meter (m^3) of water consumed including different controls:

$$Log(y_{i,t}) = \beta Log\ (x_{i,t}) + \gamma Z_{i,t} + \tau_t + \delta_i + \varepsilon \quad \text{(eq.6)}$$

where:

$y_{i,t}$ is the volume of water demanded per ha for each plot *i* at time *t*; $x_{i,t}$is the water price per m^3 of water used for the plot; $Z_{i,t}$ is a set of control variables and namely the seasonal aridity index (AI) for the plot as in Kounduri et al. (2006), but calculated as in CGIAR (2019). Moreover, the type of crop cultivated on the plot (dummy); the irrigation system used for the plot (dummy) and the water basin specified in sub-zones (dummy) have been used as control variables. τ_t is a year dummy variable for the time effect absorbing macroeconomic exogenous effects and δ_i is the individual fixed effect for considering individual unobserved heterogeneity which could lead to problems of endogeneity causing biased and inconsistent estimation of the coefficients, ε is the idiosyncratic error with zero mean and σ^2 variance (Wooldridge, 2010).

Quarterly AI for different seasons[1] have been employed as a climatic variable of control computed as the ratio of the value of the accumulated precipitation (measured in mm) of a specific season and reference accumulated evapotranspiration (measured in mm) (Allen and FAO, 1998; Villalobos et al., 2016) for each season resulting as a unit less proxy measure of the water crop requirement satisfied by seasonal rainfall (Allen and FAO, 1998; CGIAR, 2019). The data used are from the ERA-Interim dataset of the European Centre for Medium-Range Weather Forecasts (ECMWF) with a definition at cell level of 25Km^2 spatial resolution (ECMWF, 2020). Values of AI lower than 1 indicate that precipitation in the considered period did not satisfied crop water requirement, whereas value higher than 1 indicated that accumulated rainfall for the period were higher than accumulated reference evapotranspiration (CGIAR, 2019). Level of AI less than 0.65 indicate arid areas (CGIAR, 2019).

Crop types have been divided into main macro categories present in the area and namely divided into: Alfalfa, Maize, Meadows, Orchards (Apple, Pear, Peach, Plum and mixed orchards), Soya, Sugar Beet, Tomato, Vineyard and Watermelon. Irrigation systems have been divided into macro categories of irrigation used on the plots as Drip, Sprinkler and Furrow. Both crops and irrigation technology are fixed for the crop during one year, but they might change among the years.

We tested for heteroscedasticity and autocorrelation of the data using a White test and Wooldridge test both respectively indicating that data is heteroscedastic and serially correlated (Wooldridge, 2010). In order to solve this problem for having consistent estimations we used clustered robust standard errors at plot level (Bertrand et al., 2004; Gehrsitz, 2017; Mieno and Brozović, 2017) which relaxed the assumption of homoscedasticity allowing for cross-section change in the individual variance and correlation within individual groups (Hansen, 2007a) which lead to consistent estimations when the dimension of the panel is large and with a sufficient number of clusters (Hansen, 2007b). Moreover, for robustness check we ran the model using a Feasible General Least Squares (FGLS) which accounts for first-order autoregressive disturbance term producing unbiased, robust and consistent estimation with disturbances in the variance-covariance matrix (Hansen, 2007a).

The baseline econometric and the FGLS models have been applied to the whole sample and then to different subsamples in order to analyze different patterns of elasticities among irrigation technologies and crops. Moreover, the same analysis has been made for subsamples of the most representative combinations of crop and irrigation technologies.

In order to conserve information on the whole demand curve and avoiding truncation and deletion of data, water prices with zero values occurring when flat tariffs have been applied for certain plots have been transformed as the logarithm of zero is not defined (Weninger, 2003). The transformation in order to reduce bias follow other empirical studies which had dealt with logarithmic functions adding a very small quantity to zero values (Friedlaender et al., 1983; Gilligan and Smirlock, 1984; Kim, 1987). Those studies suggest to add a value in the order of 0.001 or the ten percent of the sample mean in order to not alter the distribution and consequently the logarithmic transformation (Bellégo and Pape, 2019). The zero values in our datasets are the 8.5% of the total and even if they are a residual part of the data we decided to transform them in order to do not truncate our sample. As our analysis deals with prices close to 0 with two digits we checked the effect of the transformation on the logarithmic function with different simulations. We opted for adding the ten percent of the minimum value in the distribution to reduce the noise in data due by the transformation. Finally, we made some sensitivity check for considering the robustness of the transformation and avoiding change in the structure of the model (Bellégo and Pape, 2019) looking at the kernel density estimation of the within transformation distribution of both the estimated dependent and the independent variable which fit a normal distribution.

[1] Aridity indexes have been calculated as $AI_{season} = AccumPricip/ ET0$ for each season. Seasons have been divided as Winter January, February, March. Spring April, May, June. Summer July, August, September. Autumn October, November, December.

4- Results

We found general water demand inelastic to price as values of the estimated coefficients are all below one, which indicates the demand for water is not proportionally responsive to changes in water price. Considering the whole sample analyzed, in which different crops and technologies are present, a change of one percent in water price induce an average reduction of 0.27 per cent in the water demanded at plot level. This result is consistent with previous studies which indicated general inelastic water demand in agriculture such as the meta-analysis by Scheierling et al (2006) who found an average price elasticity of -0.48. Results of the model estimations for the whole sample and sub-samples of irrigation technologies are in Table 1, for sub-samples of crop in Table 2, for representative combination of irrigation technologies and crop in Table 3. In each table are highlighted the estimation of the elasticities for both the main Log-Log model and for the FGLS for robustness control. The results of the estimations are very similar for the two econometric models indicating that our econometric estimations are robust. Only slight differences in the estimations of the two models arose for Orchard and Sugar beet.

Even if generally water demand has been estimated as inelastic, few differences arise among technologies and crops. Considering technologies sub samples (Table 1) furrow irrigations systems are the most inelastic with a coefficient of -0.208, whereas sprinkler and drip irrigation systems shown slightly higher responsiveness to changes in water price with coefficient respectively of -0.326 and -0.435 (Table 1), we try to find explanation to this finding in the next section.

Considering single crops water elasticities change (Table 2). Cattle grazing crops (Alfalfa and Meadows) which are irrigated principally with furrow irrigation are strongly inelastic. Sugar beet and Maize also have a strong inelastic water demand curve even if their main irrigation system is sprinkler. Conversely Watermelon (Drip) and Tomato (Sprinkler) are more responsive to price and their water demand curve result less inelastic with -0.5 of elasticity. This could partially depend by the water intensity of vegetables compared to grazing crops and by the higher marginal value of productivity of water as an input in vegetable productions. In fact, Alfalfa and Meadows are principally cultivated as an input for dairy farms which in this area produce Parmigiano Reggiano. Considering the value chain of Parmigiano Reggiano, water costs represent just a negligible part of total costs of productions, conversely for vegetables (such as Tomato and Watermelon) which are directly sold on the market the cost of water on final products total costs are higher. Therefore, Tomato and Watermelon (as other vegetables) water demand function should be more elastic than for cattle grazing crops as the embedded value of water in the final product is higher (Renault, 2002).

Vineyard is generally inelastic, also in this case considering irrigation technology furrow irrigation (-0.273) is more inelastic than sprinkler (-0.382), whereas the coefficient for drip irrigation are non-statistically significant. This result can depend by the high level of irrigation needed for wine production which is a high value agri-food product in which water is an essential input and with the tariffs applied by the CEWD it represents just a small part of the final cost.

Orchard have puzzling results. They have not statistically significant estimated coefficients for the Log-Log model, whereas for the FGLS the estimated coefficients indicate elastic water demand to price at 10% of significance for all types of irrigation systems and at 5% for drip irrigation. Elasticity of Orchard was as expected as they are high value crops highly water intensive, anyway considering differences in the results of the estimations in the two models this result should be taken cautiously. The different results could depend by the fact that different type of crops have been considered within the Orchard category.

Even if the main findings shown a general inelastic water demand, our estimations indicate that the response of water use to price changes for irrigation systems and crops. Moreover, differences to theoretical models may depend also by the fact that theoretical models mainly operate in range of price values higher as mostly they use simulation of prices with Mathematical Programming methods. The level of prices used in this study is quite low (between 0 and 0.048) and they are in the bottom part of the demand curve where literature on threshold elasticity says that water demand is more inelastic (de Fraiture and Perry, 2007).

Table 3. Estimation of water elasticity to price for the whole sample and for sub-sample of irrigation technologies.

VARIABLES	(1) Total Sample	(2) Drip	(3) Sprinkler	(4) Furrow
Dependent Variable				
Log (Water m^3 per HA)				
OLS				
Log (Water price)	-0.268***	-0.435***	-0.326***	-0.208***
	(-25.54)	(-5.649)	(-17.92)	(-16.01)
FGLS				
Log (Water price)	-0.276***	-0.417***	-0.354***	-0.215***
	(-24.91)	(-6.293)	(-17.88)	(-17.03)
OLS				
Constant	5.254***	7.074***	4.947***	5.105***
	(17.35)	(5.788)	(11.10)	(8.773)
Observations	28,738	2,670	16,726	9,342
R-squared	0.230	0.245	0.228	0.273
Number of ID Plot	9,097	817	6,284	2,495
Robust S.E. (Clustered)	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes
Aridity Index	Yes	Yes	Yes	Yes
Irrigated Area	Yes	Yes	Yes	Yes
Crop Type	Yes	Yes	Yes	Yes
Irrigation Technology	Yes	Yes	Yes	Yes

Robust t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4. Estimation of water elasticity for sub-samples of different crops.

VARIABLES	(1) Alfalfa	(2) Maize	(3) Meadows	(4) Orchards	(5) Vineyard	(6) Watermelon	(7) Tomato	(8) Sugar Beet	(9) Soya
Dependent Variable									
Log (Water m^3 per HA)									
OLS									
Log (Water price € per m^3)	-0.287***	-0.295***	-0.192***	-0.141	-0.329***	-0.555***	-0.565***	-0.299***	-0.280
	(-11.37)	(-7.841)	(-13.12)	(-0.674)	(-5.347)	(-5.305)	(-7.578)	(-3.357)	(-1.340)
FGLS									
Log (Water price € per m^3)	-0.586***	-0.278***	-0.219***	-1.079***	-0.342***	-0.527***	-0.371*	-0.693***	0.412
	(-16.55)	(-6.227)	(-16.42)	(-2.902)	(-8.614)	(-4.357)	(-1.782)	(-3.884)	(1.166)
OLS									
Constant	6.214***	9.635***	142.4	73.13	-80.82	-584.0	-1,432	-43.96	-494.0
	(36.57)	(7.977)	(1.157)	(0.286)	(-1.131)	(-0.709)	(-1.324)	(-0.0962)	(-0.632)
Observations	3,584	4,095	6,046	2,100	10,787	312	571	818	425
R-squared	0.162	0.224	0.298	0.371	0.211	0.297	0.311	0.236	0.122
Number of ID Plot	1,925	2,185	1,523	454	2,895	129	348	569	327
Robust	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Aridity Index	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Irrigated Area	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Crop Type	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Irrigation Technology	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust t-statistics in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 5. Estimation of water elasticity to price for sub-samples of representative combinations of irrigation technologies and crops.

VARIABLES	(1) Alfalfa Sprinkler	(2) Alfalfa Furrow	(3) Maize Sprinkler	(4) Meadows Furrow	(5) Orchards Drip	(6) Orchards Sprinkler	(7) Tomato Sprinkler	(8) Watermelon Drip	(9) Sugar Beet Sprinkler	(10) Vineyard Drip	(11) Vineyard Sprinkler	(12) Vineyard Furrow
Dependent variabl Log (Water m^3pe Ha)												
OLS												
Log (Water price)	-0.311***	-0.127	-0.304***	-0.190***	-0.0690	-0.836	-0.533***	-0.523***	-0.291***	-0.145	-0.382***	-0.273***
	(-10.18)	(-0.519)	(-8.030)	(-12.91)	(-0.447)	(-0.701)	(-7.457)	(-4.576)	(-3.179)	(-0.427)	(-3.753)	(-4.304)
FGLS												
Log (Water price)	-0.324***	0.381	-0.282***	-0.217***	-1.020**	-0.741	-0.425**	-0.494***	-0.694***	-0.00640	-0.502***	-0.247***
	(-6.995)	(0.805)	(-6.128)	(-16.32)	(-2.103)	(-1.351)	(-2.355)	(-3.832)	(-3.837)	(-0.0397)	(-8.462)	(-4.688)
OLS												
Constant	151.4	419.8	332.2**	139.6	-363.5	260.5	-629.0	-318.8	-24.19	36.95	-61.57	7.659
	(0.784)	(0.459)	(2.058)	(1.140)	(-0.755)	(0.875)	(-0.856)	(-0.353)	(-0.0526)	(0.158)	(-0.592)	(0.0622)
Observations	3,339	235	3,947	5,895	712	1,352	486	236	796	1,578	6,178	3,031
R-squared	0.217	0.175	0.233	0.306	0.339	0.438	0.418	0.311	0.242	0.245	0.198	0.254
Number of ID Plot	1,802	137	2,113	1,456	173	322	306	91	553	470	1,834	841
Robust	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Aridity Index	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Irrigated Area	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Crop Type	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Irrigation Technology	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5- Discussion and conclusions

Many studies found water demand inelastic to price (Scheierling et al., 2006), with our study we principally confirm that. Our results are interesting also for policy making highlighting that farmers in the CEWD are not proportionally respondent to water prices therefore water tariffs can be effective strategies to cope with over-irrigation issues only if they increase substantially actual water prices. Even if water demand is generally inelastic it does not mean that farmers do not respond at all to pricing policies, but it indicates they are less than proportionally responding to price changes. We have to highlight that the elasticities which we had estimated are average elasticities considering actual prices which are very low and placed in the very bottom part of the demand curve which is characterized by low elasticity (de Fraiture and Perry, 2007). Moreover, we analyzed the short term elasticity of water demand and with different ranges of prices and different timeframe results could have been different. Other empirical works in water districts where higher level of prices are adopted and with longer dataset in time could answer to this question.

Our findings shown that in the CEWD differences on water demand elasticities arose among irrigation technologies and crops. Considering irrigation technologies, the main point could be related to irrigation uncertainty due to the level of controllability of irrigation which is strictly linked to irrigation risks and uncertainty on agricultural productions. In fact, farmers do not produce in a deterministic world, but they are strongly affected by stochastic processes in irrigation decisions which are influenced by other elements than just water price such as endogenous factors as culture, social factor, expectations and exogenous factors such as climate, weather, market conditions and agri-food value chains.

Our estimated elasticity considering all technologies and all crops suggest that drip irrigation is more elastic than sprinkler and that sprinkler is more elastic than furrow irrigation systems, which is slightly in contrast with theoretical models as Berbel et al. (Berbel et al., 2018) which indicate the opposite (2018)(lower elasticity for precision systems). Our models on crop and combination of crops and technologies confirm that pattern in which drip and sprinkler technologies are more reactive to water price than furrow. We justify these results as a matter of uncertainty and risk in farmers' irrigation decisions. We argue that a higher controllability of drip and sprinkler irrigation system result in higher reactions to price changes. Whereas furrow irrigation which has not a high level of controllability is more inelastic to price because of the risk in not covering water crop requirements with potential production losses is higher. Therefore, the reaction to price changes depends more on the ease in achieving to the maximum technical level of irrigation by the use of drip and sprinkler (Berbel et al., 2018; Berbel and Mateos, 2014), whereas farmers who use inefficient system, such as furrow, in which the control is low tend to over irrigate because of higher uncertainty on reaching the maximum technical level of irrigation.

Uncertainty is an important element in irrigation decision. In fact, the maximum technical efficiency level of irrigation most of the time is not properly known by the farmer and this fact could influence indirectly a tendency of over irrigate. The farmer over-apply water just in case the water was not abundant enough for water crop requirement considering his/her uncertainty. This increases the lower is the control on irrigation fluxes due by the system of irrigation technology adopted. Furrow is an inefficient method of irrigation with low level of control on water and, following the "just in case" farmer vision, this could influence the farmer in over-use water even with increasing water prices and our paper confirms this argument. In our study, considering technologies in order of efficiency as in Berbel et al. (2018) and Berbel and Mateos (2014)as furrow (0.60), sprinkler (0.85) and drip (0.95) the elasticities follow the opposite order linked to the level of water control as drip (the most elastic), sprinkler and furrow (the least elastic). What we argue is that the higher is the control of the irrigation system the higher is the reaction to price changes, this depend more on the ease and level of certainty for the farmer in getting to the maximum technical level of irrigation.

Crop differences in elasticity may depend on their intrinsic water requirements and water marginal value of production. For crops in which water costs are a negligible part of the total costs water demand is more inelastic, whereas for products in which its cost is a remarkable part of the final costs water demand is more elastic. This reflects the value of water used in the production as an input over the total value of the final product. Moreover, differences among crops depends on how much crops change in biomass production due to reduction in water application. In fact, herbaceous culture as cattle grazing crops react more on biomass production with water reduction than vegetables or orchards which can be managed with higher agronomic control using deficit irrigation. This strategy is suited for market oriented products (as fruits and vegetables) in which quality improvements of the productions could be more profitable than increasing quantity of productions. Therefore, this hypothesis could also justify why high value crops are more elastic to water prices than low value crops differently from what theory says.

Our results highlighted that pricing policies for reducing over irrigation should be ad-hoc tailored considering irrigation technologies and crops as they react differently to economic measure. This could be achieved properly modifying the existing parameters of the actual applied tariff as the CEWD apply a two-tier tariff in which the baseline price (0.027€ per m^3) is augmented by specific coefficients for different parameters. Crops with more inelastic water demand characterized by high levels of over-irrigation, such as Meadows, Vineyard and Maize could receive additional components of water price in order to stimulate more conservative water use. Furthermore, the introduction of an additional parameters related to the irrigation system could strengthen the efficacy of pricing policy of the CEWD with increasing coefficients proportional to their elasticity (higher coefficients for furrow and sprinklers). This could improve the effectiveness of price policies incentivizing more conservative use of water for sustainable irrigation.

Our study works with average elasticity considering the whole irrigation season, we did not consider different level of elasticities during different seasons. This could have hidden some aspects related to the effect of price on water demand within different crop growing phases, in fact blooming and growing part of the plant elasticity should be more inelastic and more elastic in the mature phase of the crop (Allen and FAO, 1998). Further studies on elasticity considering other time units less than the year could give more evidences on that.

Furthermore, our study did not consider possible non-linear effect of the price on water demand for analyzing diminishing effects of pricing policies or threshold effects, which should consider different non-linear and segmented demand curves. Further studies could analyze that giving or not evidences on non-linearity of water demand curves. In our paper we used a panel data set on water demand and prices with thousands of observations at plot level over different years. Observational data of this dimension are not common in literature and it gave the chance for analyzing agricultural water district in Emilia Romagna region of strategic importance for national production. Our findings revealed that farmers are not reactive to water prices and that water demand is inelastic to price confirming previous empirical works in this field, but with differences among irrigation systems and crops. Surprisingly we found higher elasticity in water conservation and saving technologies (drip and sprinkler) than in inefficient irrigation system (furrow), which is the opposite of what theory says. This is an interesting case study because it is based on extensive observed real data with the econometric analysis, which give the chance to compare our findings based with deterministic studies and other empirical econometric works. We used a Log-Log model with fixed effect and a FGLS for robustness of the estimations. Our results highlight the importance of setting ad-hoc water tariffs treating differently water prices technologies and crop for boosting effective strategies for conservative water use in agriculture. This could be done by the management of the CEWD by modifying the setting of the parameters used for calculating the two-tier tariff and introducing increasing coefficient related to water elasticity levels of the different irrigation technologies.

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